Phase Calibration of Microphones by Measurement in the Free-field

Qamar A. Shams, Scott M. Bartram, William M. Humphreys, and Allan J. Zuckerwar
NASA Langley Research Center, Hampton VA 23681

Introduction

Over the past several years, significant effort has been expended at NASA Langley developing new Micro-Electro-Mechanical System (MEMS)-based microphone directional array instrumentation for high-frequency aeroacoustic measurements in wind tunnels. This new type of array construction solves two challenges which have limited the widespread use of large channel-count arrays, namely by providing a lower cost-per-channel and a simpler method for mounting microphones in wind tunnels and in field-deployable arrays. The current generation of array instrumentation is capable of extracting accurate noise source location and directivity on a variety of airframe components using sophisticated data reduction algorithms [1-2]. Commercially-available MEMS microphones are condenser-type devices and have some desirable characteristics when compared with conventional condenser-type microphones. The most important advantages of MEMS microphones are their size, price, and power consumption. However, the commercially-available units suffer from certain important shortcomings. Based on experiments with array prototypes, it was found that both the bandwidth and the sound pressure limit of the microphones should be increased significantly to improve the performance and flexibility of the microphone array [3]. It was also desired to modify the packaging to eliminate unwanted Helmholtz resonance's exhibited by the commercial devices. Thus, new requirements were defined as follows:

Frequency response:	100 Hz to 100 KHz (+/-3dB)
Upper sound pressure limit:	Design 1: 130 dB SPL (THD<5%)
	Design 2: 150-160 dB SPL (THD<5%)
Packaging:	3.73 x 6.13 x 1.3 mm can with laser-etched lid

In collaboration with Novusonic Acoustic Innovation, NASA modified a Knowles SiSonic MEMS design (Figure 1) to meet these new requirements. Coupled with the design of the enhanced MEMS microphones was the development of a new calibration method for simultaneously obtaining the sensitivity and phase response of the devices over their entire broadband frequency range. Traditionally, electrostatic actuators (EA) have been used to characterize air-condenser microphones; however, MEMS microphones are not adaptable to the EA method due to their construction and very small diaphragm size [4]. Hence a substitution-based, free-field method was developed to calibrate these microphones at frequencies up to 80 kHz. The technique relied on the use of a random, ultrasonic broadband centrifugal sound source located in a small anechoic chamber. The free-field sensitivity (voltage per unit sound pressure) was obtained using the procedure outlined in reference 4. Phase calibrations of the MEMS microphones were derived from cross spectral phase comparisons between the reference and test substitution microphones and an adjacent and invariant grazing-incidence 1/8-inch standard microphone. The free-field calibration procedure along with representative sensitivity and phase responses for the new high-frequency MEMS microphones are presented here.

Experimental Set Up

The free-field substitution method utilized two reference microphones calibrated by standard methods (typically via electrostatic actuation) and a third test microphone with unknown response, and conformed with industry standards [5–7]. The technique relied on the test microphone and one of the calibrated microphones being located at precisely the same location in the test chamber. The third microphone was used as a reference to compare the sound field to which the other two microphones were exposed. For the present study, two calibrated Bruel and Kjaer (B&K) microphones, a 4136 1/4-inch pressure microphone and a 4138 1/8-inch free-field microphone were used as the references. A custom microphone holder was fabricated that allowed the 1/4-inch reference microphone to be placed in the same physical location as the MEMS test microphone (Figure 2). Because of the small size and placement of rear electrical connections on the MEMS device, a custom fixture was fabricated allowing the MEMS microphone to be held, active, in the same plane as the 1/4-inch reference. The stereolithography fixture was designed and fabricated with a rectangular recess to set the MEMS device flush with the surface, and provided electrical connections through spring-loaded contacts. The 1/8-inch reference microphone was mounted slightly below and 1/2 inch to the rear of the plane of the test and 1/4-inch microphones and held invariant allowing it to monitor the sound field.

The random sound field in the test chamber was generated using a Campanella Associates RSS-101(U) broadband ultrasonic (10 – 100 kHz) centrifugal source. The microphones were centered in the plane of the source, located 16 inches from the wind screen. The entire experimental rig was placed near the center of a small anechoic chamber such that the source and microphones were well isolated from each other and from the chamber walls. The reference microphones were powered by a dual power supply delivering a 200-volt polarization voltage, while the MEMS microphones were powered via a regulated 3-volt DC source. Data was acquired at a sampling rate of 200 kHz using an instrumentation recorder providing 16 bits of digitization. Lowpass filters set to 80% of the Nyquist frequency were employed in the system to prevent aliasing, and external gains of 40 dB were applied to all microphones to increase the number of usable digitization bits. Calibration sessions consisted of two 20-second data acquisition runs, one with the 1/4-inch reference microphone mounted in the chamber and the second with the test microphone mounted. The data was processed in Matlab to extract the sensitivity and phase responses of the test microphones using cross spectral difference methods.

To estimate the uncertainty of the free-field calibration technique, a pressure cavity calibration was performed on the MEMS microphones using a B&K 4226 multifunction calibrator. The calibrator was modified to allow access to the driving signal, allowing computation of the phase response of the microphone. The MEMS microphones were held in the cavity calibrator using the same fixture used in the free-field test to minimize installation-induced anomalies in the measured response.

Results

A total of 17 MEMS microphones (eight of design #1 and nine of design #2) were calibrated using the free-field and pressure cavity techniques. A representative plot of the sensitivity and phase response for one of the microphones as measured by the free-field technique is shown in Figure 3. From DC to 40 kHz a slight oscillatory fluctuation is shown in the responses, most

likely due to weak standing wave patterns present between the source and microphones. Note that the use of a centrifugal broadband source produces much less standing wave interference than does the use of standard speakers for this type of calibration (see reference 4). The degradation in the response above 70 kHz is believed to be caused by the anti-aliasing filters employed in the data system. The response of the MEMS microphone is remarkably flat across the entire broadband frequency range, implying that any cavity or diaphragm resonance's if they exist will occur at frequencies significantly higher than 80 kHz, verifying the device's frequency response design goal.

Summary

The free-field substitution method has historically been shown to be effective for determining with high precision the sensitivity response of test microphones. The present work has extended the traditional substitution technique to allow the phase response of test microphones to be obtained with reasonable accuracy. The proposed new method is especially valuable for calibration of microphones which are unsuited for the electrostatic actuator method. As a test of the method, an ensemble of newly-designed, high-frequency MEMS microphones were calibrated using the new technique. Although the data analysis is continuing, the early results indicate that the proposed technique can be used to simultaneously obtain the sensitivity and phase responses of test microphones with reasonable accuracy. Future research will focus on quantifying the uncertainty of the calibration technique as well as apply it to various classes of microphones.

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References

1. Brooks, T.F., Humphreys, W.M., Jr., Flap-edge Aeroacoustic Measurements and Predictions, *Journal of Sound and Vibration*, Volume 261, pp. 31-74, 2003.
2. Mendoza, J.M., Brooks, T.F., Humphreys, W.M., Jr., An Aeroacoustic Study of a Leading Edge Slat Configuration, *International Journal of Aeroacoustics*, Volume 1, No. 3, pp. 241-274, 2002.
3. Humphreys, W.M., Jr., Shams, Q.A., Graves, S.S., Sealy, B.S., Bartram, S.M., and Comeaux, T., Application of MEMS Microphone Array Technology to Airframe Noise Measurements, *AIAA Paper 2005-3004, 11th AIAA/CEAS Aeroacoustics Conference*, Monterey, CA, 2005.
4. Zuckerwar, A.J., Herring, G.C., and Elbing, B.R., Calibration of the Pressure Sensitivity of Microphones by a Free-Field Methods at Frequencies up to 80 kHz, *J. Acoust. Soc. Am.*, Volume 119, Number 1, pp. 320-329, 2006.
5. ANSI S1.15-2005/Part 2, Measurement Microphones – Part 2: Primary method for Pressure Calibration of Laboratory Standard Microphones by the Reciprocity Technique, *Standards Secretariate, Acoustical Society of America*, Melville, NY, 2005.
6. CEI/IEC 61094-5: 2001, Measurement microphones – Part 5: Methods for pressure calibration of working standard microphones, *International Electrotechnical Commission*, Geneva, 2001.
7. CEI/IEC 61094-6: 2004, Measurement microphone – part 3: Electrostatic actuators for determination of frequency response, *International Electrotechnical Commission*, Geneva, 2004.

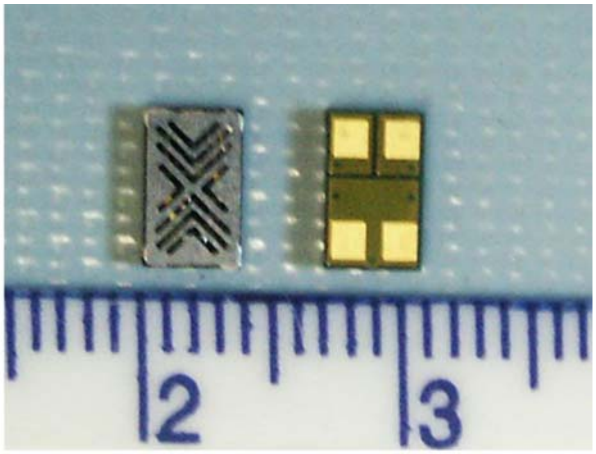

Figure 1. Customized High Frequency MEMS Microphones (Front and Rear Views).

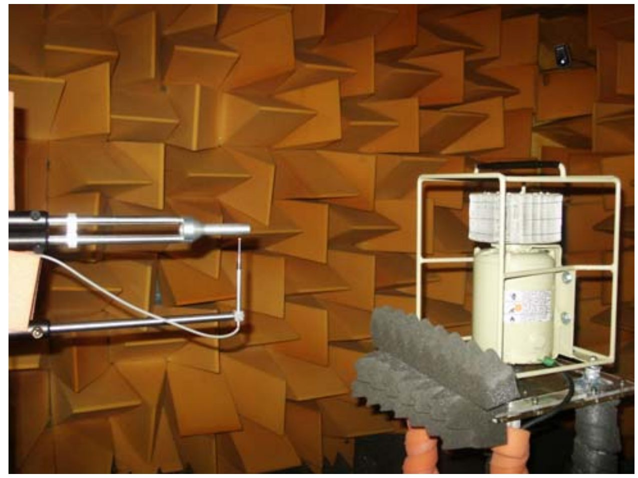

Figure 2. Calibration Rig in Test Chamber.

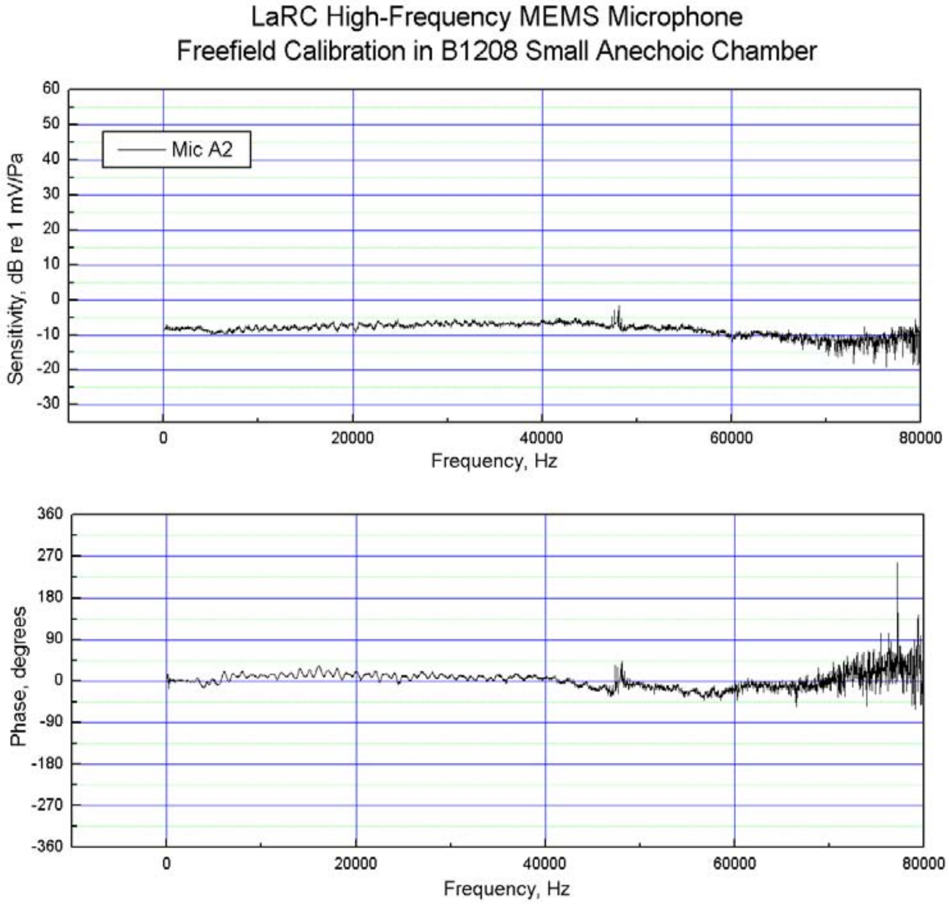

Figure 3. Representative Free-Field Response for MEMS Microphone.